Coupling between the convection and boundary layer schemes in the UKMO unified model

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1 Introduction

The boundary layer and convection schemes within the UKMO unified model act independently. This can lead to unexpected changes in the vertical transports of moisture when parameters within the convection scheme are altered. An example of this, based on a case study of shallow convection in the trade wind region, is described below.

2 Case study

Siebesma and Cuijpers (1995) describe a study of shallow convection using a large eddy simulation. The study used large scale tendencies and profiles derived from BOMEX data,with the period chosen for the study being undisturbed, and characterised by the presence of shallow cumulus convection. The large scale tendencies for temperature and humidity represent horizontal advection, subsidence and radiative cooling. The initial temperature and humidity profiles were averages from one corner of the BOMEX array (the average profiles over the whole array were not used because they smoothed the trade wind inversion too much). For the single column model runs the wind profile was specified and not allowed to change. The large eddy model succesfully simulated a steady state cumulus field. The fractional entrainment and detrainment rates diagnosed from the simulation were significantly larger than the values currently used in mass flux convection schemes. Siebesma and Holtslag (1996) used the large scale tendencies to evaluate the performance of several cumulus parametrisation schemes and found that the larger fractional entrainment and detrainment rates improved the performance of such models.

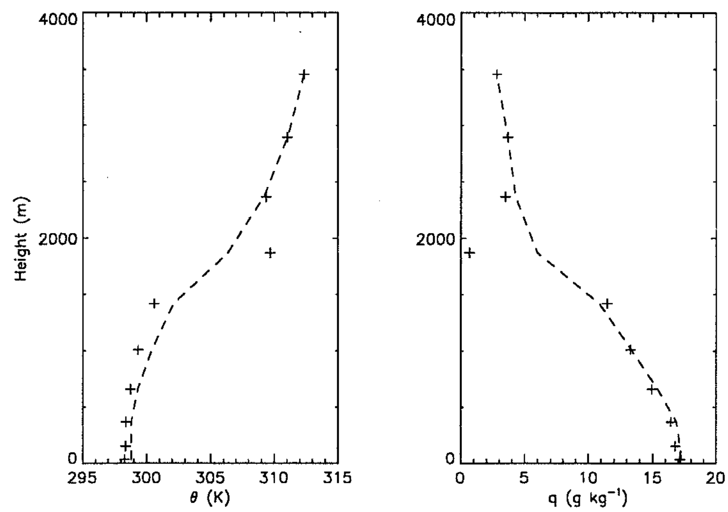

Figure 1: Potential temperature and humidity profiles obtained with the standard value of the threshold buoyancy excess. The dashed line is the initial profile, + Model profile.

3 The UKMO model

The convection scheme used in the UKMO unified model is a mass flux scheme described by Gregory and Rowntree (1990). The closure for the scheme is based on the buoyancy of lifted parcels rather than an assumed moisture budget for the subcloud layer. Convection is assumed to occur if the buoyancy of a lifted parcel exceeds a threshold value. For the results to be presented the fractional entrainment and detrainment rates used in the model were increased in line with the values diagnosed from the large eddy simulations. This improved the agreement between the modelled and observed temperature and humdity profiles, in accord with the results presented by Siebesma and Holtslag (1996) for other models.

4 Results

Figure 1 shows the steady state temperature and humidity profiles from the single column model forced by the BOMEX tendencies. The agreement between the observed and modelled profiles is reasonably good, although there is a slight tendency for the model to cool and dry below the inversion, These changes could reflect errors in the largescale tendencies and/or the initial profile. The warming and drying at the top of the trade inversion arise because the large scale tendencies are not being balanced by the convection scheme. For these runs, only the entrainment and detrainment parameters have been altered in the model, and the results indicate that the way in which the convection scheme distributes heat and moisture in the inversion layer also needs to be retuned. Figure 2 shows the moisture flux profiles diagnosed from the convection and boundary layer schemes. The convection scheme does not contribute to the moisture transport in the subcloud layer, all of the transport is associated with the boundary layer scheme. Within the cloud layer the flux from the convection scheme decreases linearly with height, the moistening due to the flux divergence balancing the large scale tendencies. The boundary layer scheme is also responsible for some transport in the cloud layer. This occurs because the formulation of the stability dependence of the eddy viscosities does not incorporate a critical Richardson number. However, the form of the flux profile (parabolic with zero fluxes at the top and the bottom of the layer) will tend to reduce the humdity gradient in the cloud layer, but will not change the layer averaged humidity.

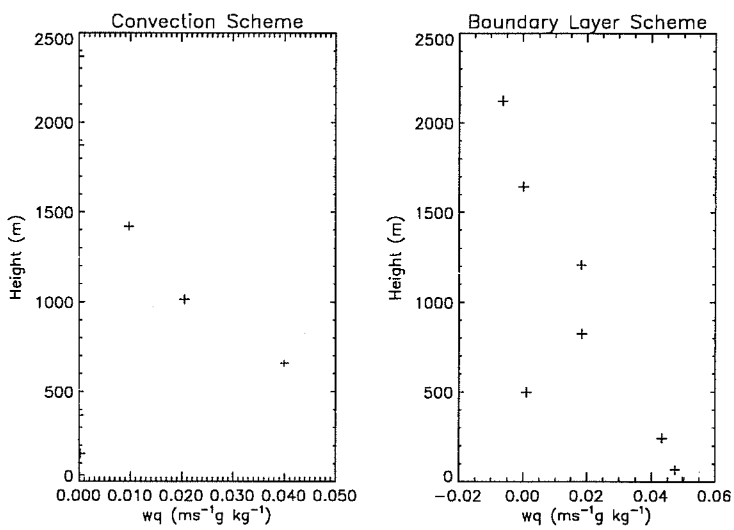

Figure 2: Moisture flux profiles diagnosed from the convection and boundary layer schemes.

The convection in this case starts from the third model level, just below cloud base, rather than from the levels closer to the surface as might be expected given the conceptual basis of the buoyancy closure. The reason is that the enhanced entrainment rate leads to buoyancy excesses for lifted parcels that are less than the critical value required to initiate convection. However, the latent heat release that occurs when air from level 3 is lifted to level 4 provides a sufficiently large buoyancy excess for convection to be diagnosed.

Reducing the threshold buoyancy excess required for convection to be initiated leads to only small changes to the temperature and humidity profiles (Figure 3). However, the roles played by the boundary layer and convection schemes in the vertical transport of moisture changes quite markedly as shown in Figure 4. There is now a small moisture flux associated with the convection scheme in the subcloud layer, but the boundary layer scheme is still responsible for most of the transport. However, compared to the previous case the moisture flux due to the convection scheme near cloud base is much smaller and a large fraction of the moisture transport from the subcloud to cloud layer is maintained by the boundary layer scheme.

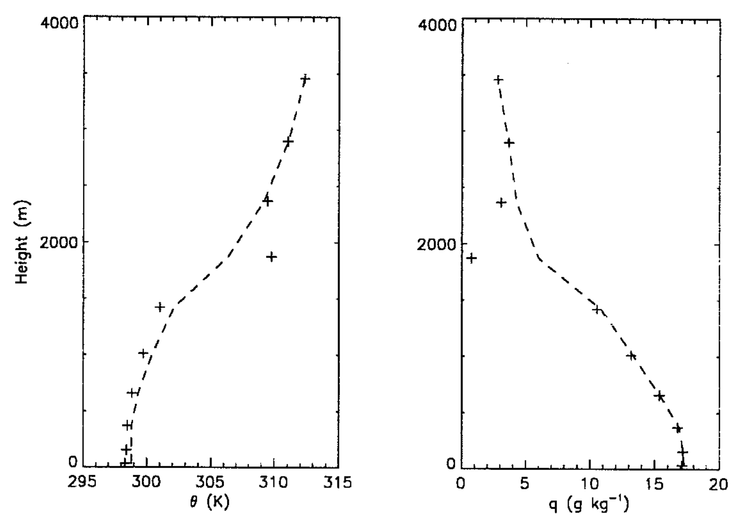

Figure 3: Potential temperature and humidity profiles obtained with a reduced value of the threshold buoyancy excess.

5 Conclusions

The results described above show that small changes to an internal parameter within the UKMO convection scheme can lead to large changes in the partitioning of the vertical transport of moisture between the convection and boundary layer schemes, for shallow convection. This change is not accompanied by significant changes to the temperature and humidity profiles. This suggests that in testing convection schemes, particularly for shallow convection, it is not enough to ensure that they reproduce observed temperature and humidity profiles closely, but that the partitioning of the vertical transports of heat and moisture between different schemes is also reasonable.

The undesirable coupling between the boundary layer and convection schemes in the UKMO model arises because the interactions between the physical processes being represented are not modelled. The two schemes are coupled through the large scale temperature and humidity fields. However, the processes that the schemes represent overlap to some extent and occur on similar time and space scales so that the interaction is more direct and should be represented explicitly within the schemes.

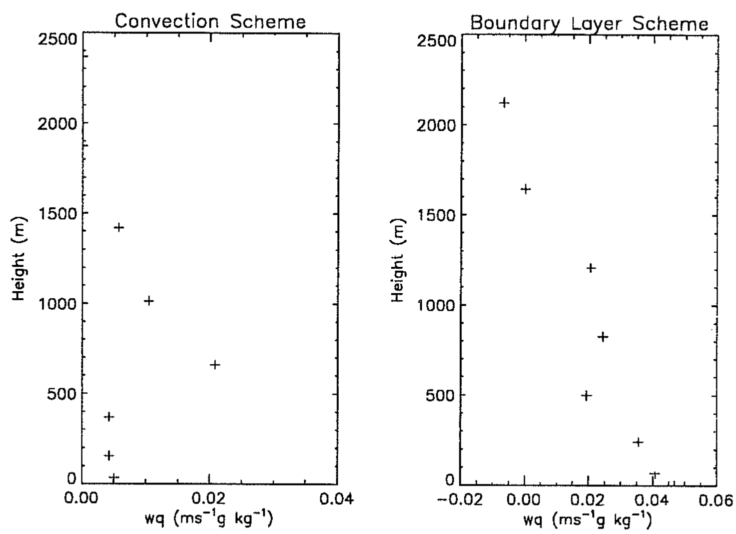

Figure 4: Moisture flux profiles diagnosed from the convection and boundaru layer schemes.

6 References

Gregory, D. and Rowntree, P. R., 1990: A mass flux convection scheme with representation of cloud ensemble characteristics and stability dependent closure. Mon. Wea. Rev., 118, 1483-1506.

Siebesma, A. P. and Cuijpers, J. W. M., 1995: Evaluation of parametric assumptions for shallow cumulus convection. J. Atmos. Sci., 52, 650-666.

Siebesma, A. P. and Holtslag, A. A. M., 1996: Model impacts of entrainment and detrainment rates in shallow cumulus convection. J. Atmos. Sci., 53, 2354,2364.